Investigation of Microclimate and Air Pollution in the Classrooms of a Primary School in Wuhan

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Abstract

Field campaigns were conducted in autumn and winter of 2013, respectively, to investigate indoor microclimate and air pollution in four naturally ventilated classrooms for the sixth-grade students at a primary school in Wuhan's urban area. The experimental results showed that indoor air temperature was 13-22 °C in autumn and 5-22 °C in winter, while mean RH was around 55% in autumn and 40% in winter, respectively. Indoor carbon dioxide (CO\textsubscript{2}) level varied in the range from 500 ppm to 1123 ppm during school time. Formaldehyde (HCHO) and total volatile organic compounds (TVOCs) concentrations were low and at acceptable levels, but indoor PM\textsubscript{1.0}, PM\textsubscript{2.5} and PM\textsubscript{10} levels were the same as outdoor, up to 325 µg/m\textsuperscript{3} 332 µg/m\textsuperscript{3} and 411 µg/m\textsuperscript{3} in autumn, and 899 µg/m\textsuperscript{3} 927 µg/m\textsuperscript{3} and 1090 µg/m\textsuperscript{3} in winter, respectively. According to the results, low air temperature and poor ventilation made issues of concern for the students in the classrooms in winter. In addition, indoor air pollution caused by PM was further elevated in winter due to severe ambient air pollution

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1. Introduction

Children are considered to have greater susceptibility to air pollutants than adults, because they breathe higher volumes of air relative to their body weights and their tissues and organs are actively growing [1]. Accordingly, allergic respiratory diseases, such as asthma and rhinitis have been found increased among children [2]; and today, asthma is of great concern in children health, as up to 1/3 of children in some regions have been diagnosed with asthma [3].

Exposures to indoor air pollutants, such as particulate matter (PM), formaldehyde (HCHO), volatile organic compounds (VOCs) have been associated with the children's respiratory health such as asthma, allergy and airway inflammation [4,5,6]. In China, a number of studies have investigated indoor pollution in the classrooms, where children spend most of their daytime [7,8,9]. This paper is an additional contribution focusing on air pollutants in indoor microclimate and air pollution in the classrooms of a primary school in the general urban area.

2. Methods

![Fig. 1. (a) primary school; (b) classroom.](image)

We conducted the field experiments in four classrooms on a four-storeyed teaching building of a primary school as shown in Fig. 1: one classroom (S1) around the corner on the second floor and three classrooms (S2, S3 and S4) along the same corridor on the third floor. The building was naturally ventilated with ceiling fans and separated air conditioners installed in each classroom for indoor thermal control. The measurements were done in the autumn and winter of 2013, respectively, to examine the changes in indoor climate and air pollution caused by the seasonal climate variation. The field investigation included three tasks: (1) monitoring of air temperature, relative humidity (RH) and CO₂ level; (2) measurement of PM mass concentration; (3) test of HCHO, acetaldehyde, and VOCs in air. Task (1) lasted for two weeks to characterize the indoor climate in four classrooms in the seasons. Task (2)–(3) were carried out when we visited the primary school to set up the instruments for Task (1) on November 11th and December 19th.

2.1. Monitoring of air temperature, RH and carbon dioxide (CO₂) concentrations

The data loggers with temperature and humidity sensors (T&D TR-71Ui&TR-72Ui; ESPEC Thermal Recorder RS-11) were used to monitor air temperature and RH at an interval of 10 min for 2 weeks. In each classroom, the data loggers were placed at three positions: 0.1 m (H0.1 m) and 1.1 m (H1.1 m) in the front of classrooms, and outdoors in the corridor. CO₂ concentration was monitored at an interval of 5 min for 2 weeks with the data logger (Lutron MCH-383SD) placed on the ground at the corner, to avoid the direct influence of people's exhalation. Outdoor CO₂ concentration was left out because it normally varied at relatively small levels that cannot lead to the high indoor CO₂ levels of concern.

2.2. Measurement of PM mass concentrations
We measured mass concentrations of PM$_{1.0}$, PM$_{2.5}$, and PM$_{10}$ in the front and back of the classrooms, and outdoors in the corridor, at an interval of 1s for three minutes using the aerosol monitor (TSI 8534 DustTrak). In the experiment, the instrument was placed approximately 1.1 m from the ground, i.e. the height of the mouth of seated people, with attention to avoid the direct influence of respiration.

It should be noted that TSI 8534 measures PM concentrations with a light scattering technique, where the amount of scattered light is proportional to the volume concentration of the aerosol. Affected by RH [10] and hydrophilic particles such as sulfate, nitrate and some organic PM particles [11], the PM concentration obtained by this instrument are not actual gravimetric values. The Australia researchers presented a linear regression equation to convert the PM$_{2.5}$ concentration obtained by TSI 8534 into the values by the instrument with the principle of gravimetric sampling method [12].

$$\text{PM}_{2.5}^{\text{gravimetric}} = 0.394 \times \text{PM}_{2.5}^{\text{light}} + 4.450 \quad (\text{with } R^2 = 0.83)$$  \hspace{1cm} (1)

The unit of PM$_{2.5}$ concentration is $\mu g/m^3$ in the equation. In this paper, Equation (1) was used to convert the PM$_{2.5}$ concentrations obtained by TSI 8534 into the values assumed to be obtained by a gravimetric sampler, in order to make the comparison with the relative national standards on ambient air quality.

2.3. Sampling and analysis of HCHO, acetaldehyde, and VOCs

The potable air sampler with a mini pump (SIBATA MP-Σ300) was applied for sampling air at the heights of around 1.1 m from the ground, with a sampling rate of 1 L/min for 30 min. Air samples for testing HCHO and acetaldehyde were contained in active gas tubes (SIBATA, DNPH active gas tube), and those for VOCs test were collected in solid phase samplers (SIBATA, Charcoal tube standard). After finishing the sampling, the tubes were tightly plugged and then sealed in the attached bag specially designed for preserving the active gas tube. Next, HCHO and acetaldehyde were analyzed with the high performance liquid chromatography (HPLC) method proposed by Japanese Standards Association [13], and VOCs were analyzed with the gas chromatography/mass spectrometry (GC/MS) methods by Japanese Standards Association [14]. TVOCs' level was a sum of the concentrations of identified VOCs, which were quantified with each calibration curve, and the concentrations of unidentified VOCs calculated using the response factor of toluene from C6 to C16.

3. Results

Following the indoor climate in terms of air temperature and RH, we will then present the results with regard to the air pollutants: CO$_2$, PM, HCHO, acetaldehyde, TVOCs. Table 1 shows the mean values of each pollutant obtained in the classrooms. Because of the trouble with instruments, we failed to get the data of CO$_2$ in autumn and some other data.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Autumn</th>
<th>Winter</th>
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<tbody>
<tr>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>CO$_2$ (ppm)</td>
<td>37</td>
<td>365</td>
</tr>
<tr>
<td>PM$_{1.0}$ (μg/m$^3$)</td>
<td>383</td>
<td>373</td>
</tr>
<tr>
<td>PM$_{2.5}$ (μg/m$^3$)</td>
<td>439</td>
<td>456</td>
</tr>
<tr>
<td>HCHO (μg/m$^3$)</td>
<td>0.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Acetaldehyde (μg/m$^3$)</td>
<td>1.2</td>
<td>1.4</td>
</tr>
<tr>
<td>TVOCs (μg/m$^3$)</td>
<td>152</td>
<td>42</td>
</tr>
</tbody>
</table>
3.1. Indoor microclimate

Fig. 2 shows the distributions of indoor and outdoor air temperature and RH. In autumn, indoor air temperature during schooltime mainly varied in the range of 13–22 °C, with the averages within 16.3 ± 1.7 °C, while RH mainly varied between 20% and 90%, with the averages within 57 ± 5%. In winter, indoor air temperature during schooltime mainly varied in the range of 5–19 °C, with the averages within 10.8 ± 1.4 °C, while RH mainly varied between 10 and 80%, with the averages within 44 ± 5%. Indoor air temperature was a little higher than outdoors in average.

3.2. CO₂ concentration

Fig. 3. CO₂ concentration in classrooms.
Fig. 3 shows the results of CO₂ concentration in the classrooms measured during schooltime when they were occupied in use in winter. CO₂ concentration usually varied between 400 and 6000 ppm. According to Table 1, the mean CO₂ concentration was more than 1200 ppm in every classroom. The maximum CO₂ concentration was found in Classroom S1 which exceeded 11000 ppm.

3.3. PM concentration

Mass concentrations of PM₁₀, PM₂.₅ and PM₁₀ directly measured by the instrument are given in Fig. 4. In accordance with the significant outdoor pollution, indoor PM levels were also very high. Especially in December, PM pollution in the classrooms was significantly exacerbated together with outdoor pollution. Most of the indoor PM concentrations exceeded the corresponding outdoor concentrations in autumn, indicating that there were considerable sources of PM pollution indoors, such as chalk powder. Moreover, as the outdoor PM concentration reached a very high level in the experimental period in December, the strength of PM source inside the classrooms indicated relatively smaller than the corresponding outdoor concentrations. This result implied that ambient PM pollution in Wuhan was in a very serious situation in the winter, and could be a decisive factor for PM level in the classrooms with an overwhelming impact.

Fig 5 shows the converted gravimetric values of PM₂.₅ concentration by using Equation 1. In autumn and winter, the gravimetric concentrations of PM₂.₅ were far more than 75μg/m³, the limit of the daily mean value of PM₂.₅, according to ambient air quality standards (GB3095-2012).
3.4. HCHO, acetaldehyde and TVOCs in air

Fig. 6 shows the concentrations of HCHO, acetaldehyde and TVOCs in air samples. The maximum HCHO concentration was 10 µg/m³ in classrooms, lower than the limit (100µg/m³) proposed by the national standards for indoor air quality standard (IAQ) [15]. Acetaldehyde concentration was maximized at 12.5 µg/m³, lower than 48 µg/m³, which was suggested for indoor environments by Ministry of Health, Labor and Welfare, Japan [16]. The averages of TVOCs were less than 600 µg/m³, the limit proposed by the national standards for IAQ. Both indoor and outdoor concentrations of HCHO, acetaldehyde and TVOCs were obviously higher in winter. Moreover, all of the indoor concentrations of HCHO and acetaldehyde were higher than the corresponding outdoor concentration.

4. Discussion

4.1. Air temperature and RH

Along with the decrease of outdoor temperature indoor temperature also decreased with mean values of around 11 °C. For the classrooms of elementary and secondary school air temperature and RH shall be in the range of 16–18 °C and 30%-80% [17] respectively. Therefore, the existing heating systems in the classrooms were not sufficient to create recommended thermal environments for the children in winter.

4.2. CO₂ concentrations

According to the indoor air quality standard [15], daily mean value of indoor CO₂ concentration must be less than 1000 ppm in occupied indoor environments. Health standard for classroom ventilation in elementary and secondary school [18] specifies that CO₂ concentration in classrooms must be less than 1500 ppm at any time. In our study, in winter, CO₂ concentration in the classrooms was measured more than 1000 ppm in over 60% of schooltime and more than 1500 ppm in 40% of schooltime. Obviously, when all of the doors and windows were closed in winter, it was insufficient to get required air exchanges in winter if merely relying on natural ventilation.

4.3. Other air pollutants

According to the results shown above, HCHO, acetaldehyde and TVOCs were kept in safe and acceptable levels in the classrooms; but indoor PM pollution was at a severe situation, especially in winter, due to the high ambient PM pollution. As shown in previous publication (GB3095-2012), the children are suffering from “heavily polluted” or “severely polluted” environments either indoors or outdoors.

In our study, the indoor/outdoor (I/O) ratio of PM₃.₅ varied in the rage of 0.84–1.23 in autumn and 0.86-0.95 in winter. The high I/O ratio suggested that most of the fine particles in the naturally ventilated indoor spaces were from outdoor air. Furthermore, PM₁₀ indicated to be the primary component of PM₁₀ as the ratio of PM₁₀ to PM₁₀ was up to 0.71-0.86 in autumn and 0.78-0.86 in winter.
5. Conclusions

Based on the comparison with the China national standards [15,17,18] on indoor and ambient air quality, this paper demonstrates that HCHO, acetaldehyde and TVOCs were low and at acceptable levels for the children's respiratory health in the classrooms. However, PM pollution was at significantly high levels with both influences of indoor and outdoor sources; in winter, the exacerbated outdoor PM pollution was the preponderant influence factor for indoor PM pollution. In addition, high CO₂ concentration and low air temperature was not beneficial to the children's learning and physical development in winter. Therefore, especially in winter, more effective HVAC system with efficient air filter is necessary to be installed to create a healthy, comfortable and productive environment in the classrooms in the primary school.

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